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MILD WIND SERIES
MINUTE STEAK EVENT [redacted]

PROJECT OFFICERS REPORT

[redacted]

TECHNICAL DIRECTORS SUMMARY REPORT

HEADQUARTERS
DEFENSE NUCLEAR AGENCY
WASHINGTON, D.C. 20305

[redacted]

Issuance date: 20 November 1972

[redacted]

79P8 94-27394

Enclosure 8

efense Nuclear Agency
6801 Telegraph Road
Alexandria Virginia 22310-3398

IMTS 23 August 1994

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MILD WIND SERIES [redacted]

MINUTE STEAK EVENT

PROJECT OFFICERS REPORT

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TECHNICAL DIRECTORS SUMMARY REPORT

HEADQUARTERS
DEFENSE NUCLEAR AGENCY
WASHINGTON, D.C. 20305

Paul A. Trimmer, Technical Director

Harry Diamond Laboratories
Connecticut Ave. and Van Ness St.
Washington, D.C. 20438

Donald E. Tiano

Nuclear Defense Research Corp.
5301 Central Ave., NE.
Albuquerque, New Mexico 87108

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ABSTRACT

[redacted] MINUTE STEAK was a Department of Defense Vertical Line of Sight (LOS) undergound [redacted] It was detonated on 12 September 1969 in drill hole U11f at the Nevada Test Site. The MINUTE STEAK program was designed to evaluate the response of military systems, subsystems, and components to [redacted] Some of the systems which were involved were Poseidon, Minuteman, Mk 3, and Spartan.

[redacted] The test was successful with most of the objectives being attained. The system experiments demonstrated survival at the threat levels and in some cases uncovered problems at higher than threat levels. The success of the transistor hardening program was demonstrated, and a greater understanding of magnetic effects and internal electromagnetic pulse (IEMP) was obtained. The fluence and spectrum were nominal.

[redacted] Caution should be observed in extracting information from this document, since certain paragraphs, figures and tables that are individually unclassified may become classified if consolidated or associated with events in this report.

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PREFACE

[redacted] This MINUTE STEAK Summary Report was prepared in accordance with DASA Circular 3000.2A, dated 19 February 1970. As such, it summarizes all MINUTE STEAK activities through its publication date. This document is complete in itself and replaces the MINUTE STEAK Interim Summary Report dated January 1970 which may be destroyed.

[redacted]he information in this report is based upon documented activities, personal notes of the authors, data presented by experimenters at a posttest meeting and experimenter-submitted project officer's reports, and personal contact with experimenters. The conclusions drawn in this report are those of the authors and have not necessarily been coordinated with nor approved by the experimenters or their organizations.

[redacted] The successful fielding of MINUTE STEAK was directly due to Col. John A. B. Bower, CDR Melvin L. Scott, Lt. Col. Ellen M. Hippeli, LCDR William Shoenholzer, Capt. Thomas Genoni, LTJG Thomas Madison, and ENS Joseph Lambert of DASA, Test Command. They overcame proficiently all the problems that are inherent in a test of this nature.

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LIST OF ILLUSTRATIONS

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LIST OF ILLUSTRATIONS (Continued)

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LIST OF TABLES

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CHAPTER 1

INTRODUCTION

[redacted]MINUTE STEAK was the sixth underground nuclear test in the MILD WIND Series. It was detonated in drill hole U11f at the Atomic Energy Commission's (AEC's) Nevada Test Site at approximately 1100 hours on 12 September 1969.

[redacted] The MILD WIND Series of tests is designed [redacted] is sponsored by the Department of Defense (DOD). Previous shots in this series were WISH BONE, 18 February 1965, DILUTED WATERS, 16 June 1965, PIN STRIPE, 25 April 1966, NEW POINT, 13 December 1966, and MILK SHAKE, 25 March 1968. [redacted]

1.1 ([redacted]OBJECTIVES. The MINUTE STEAK program was designed to evaluate the response of military systems, subsystems, and components [redacted] The overall objective was to provide data which would further establish the validity of laboratory simulation and theoretical analysis of the response of a variety of test items. The specific objectives were:

(1) Confirm levels of hardness of military subsystems, components, and materials [redacted]

(2) Confirm theoretical and laboratory hardening techniques used to design systems and components.

(3) Study the interaction of [redacted] with basic materials and components.

(4) Measure the radiation environment parameters to aid in correlating tactical and laboratory environments with the MINUTE STEAK environment.

1.2 [redacted] PARTICIPATION.

The test was conducted by the Defense Atomic Support Agency (DASA) with seven service laboratories, 12 civilian organizations, and two AEC laboratories participating. There were 19 projects consisting of 41 experiments, many

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

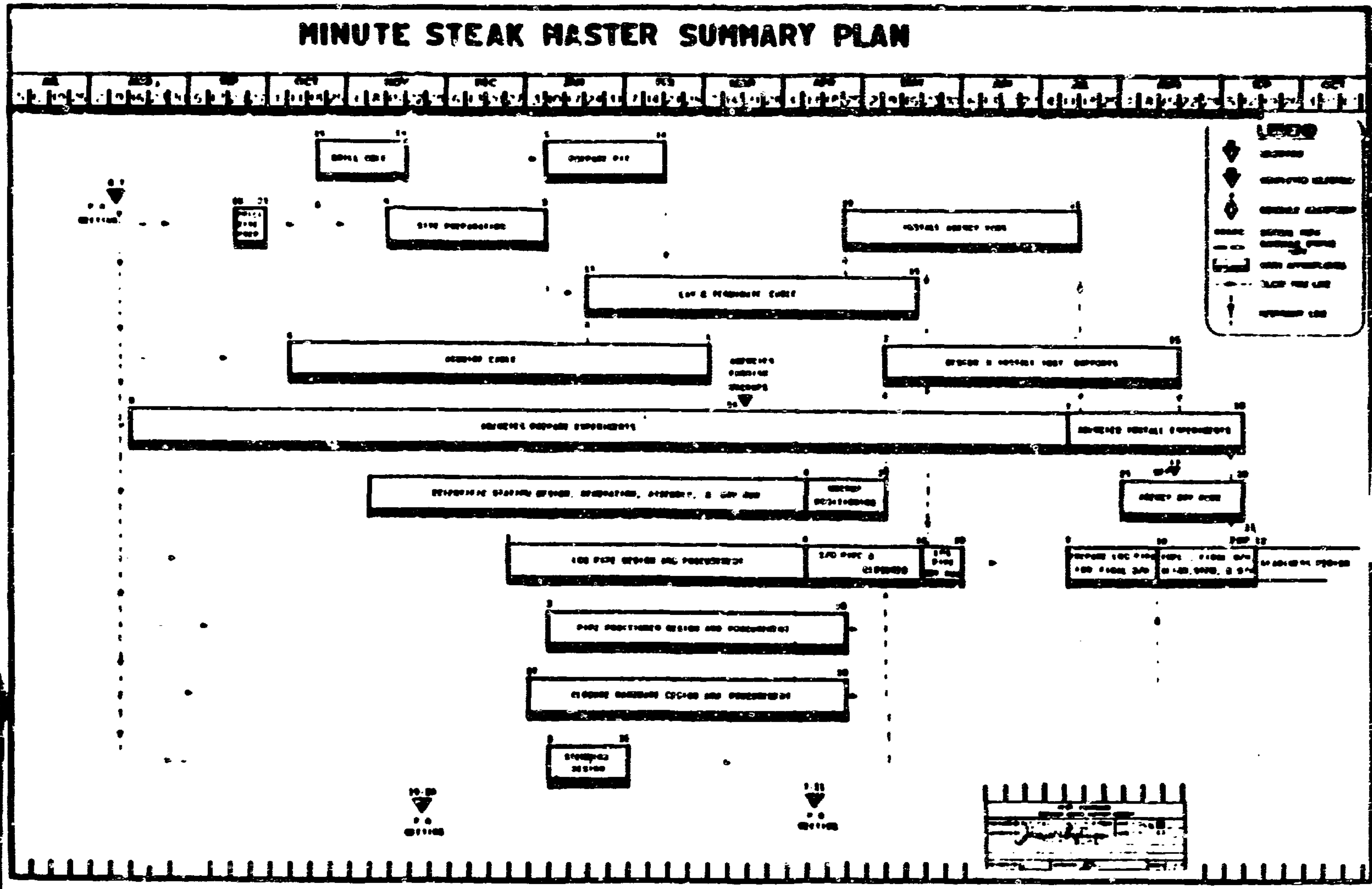

Figure 1.1 [redacted] --MINUTE STEAK master summary plan [redacted].

[redacted]

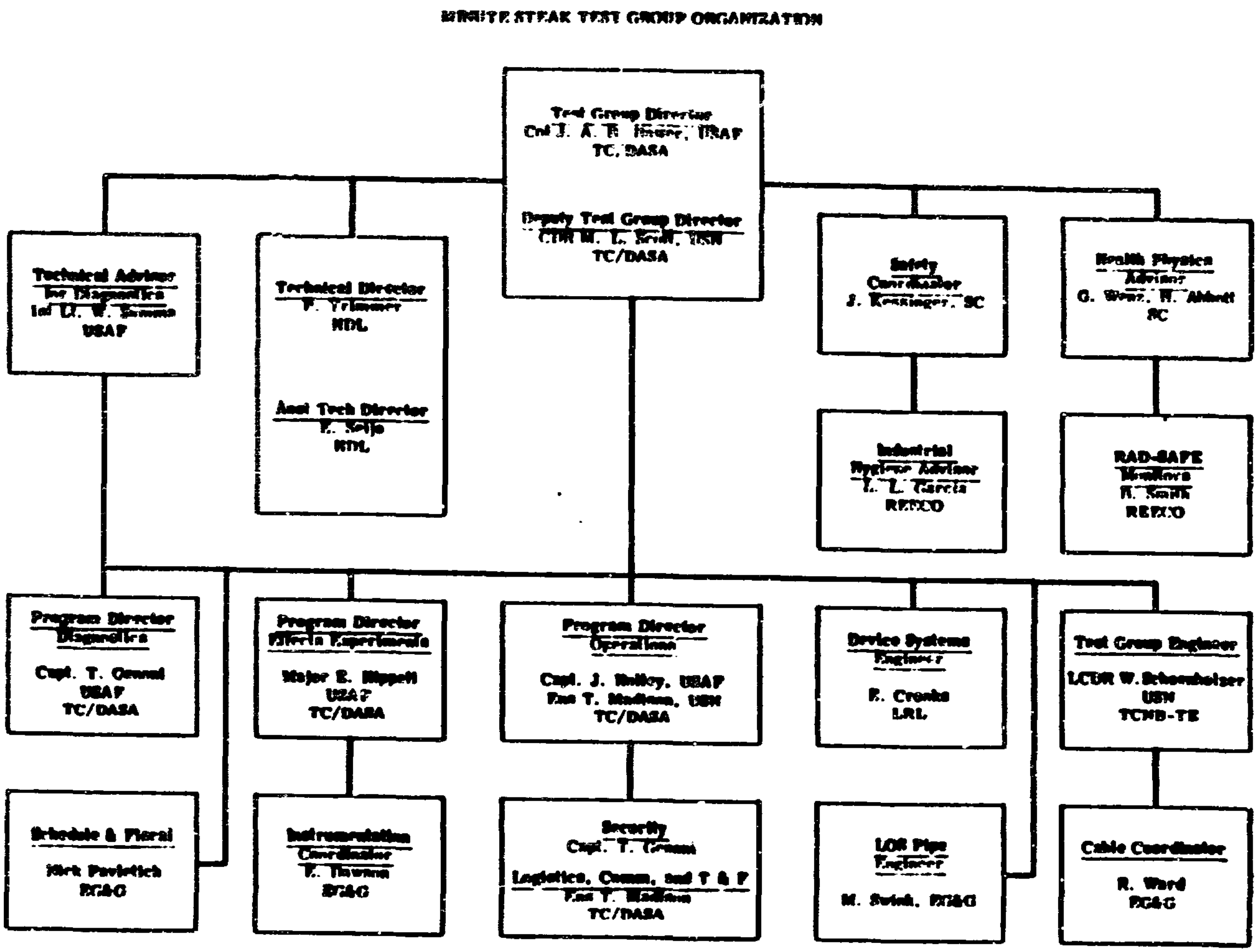

Figure 1.2 [redacted]. --MINUTE STEAK test group staff organization [redacted]

[redacted]

[redacted]

CHAPTER 2

TEST CONFIGURATION

[redacted] In this test an evacuated Vertical Line of Sight (VLOS) pipe was used as a path for the radiation from the device, emplaced underground, to the experiments located above ground. A string of closure devices was used to prevent radioactive gas and debris from reaching the atmosphere, thereby complying with the test ban treaty. [redacted] The distance from the source point to the surface was approximately 867 feet. [redacted]

The scaled depth of burial is equal to the vertical distance from the source to the surface divided by the yield to the 1/3 power.

2.1 [redacted] STEMMING AND CONTAINMENT.

[redacted]

[redacted]

Pages 6-8 are deleted

[redacted]

[redacted]

2.2 [redacted]

2.3 [redacted] TRAILER PARK. Recording instrumentation was housed in trailers located 800 feet south of ground zero. Figure 2.4 is a trailer park plan, and figure 2.5 is an aerial photograph of the trailer park. Signal cables and control cables were laid in troughs between the mobile tower and the trailers. Power to the trailers was furnished by motor generators, usually two to a trailer, one being used for instrumentation power and the other for utility power. This insured that the experiments were completely isolated from each other. All circuit breakers external to the trailers were pinned so that ground shock would not cause a loss of power. Fuzes were used, however, to prevent loss of power to the entire trailer park in case of a malfunction in one experiment.

2.4 [redacted]

[redacted]

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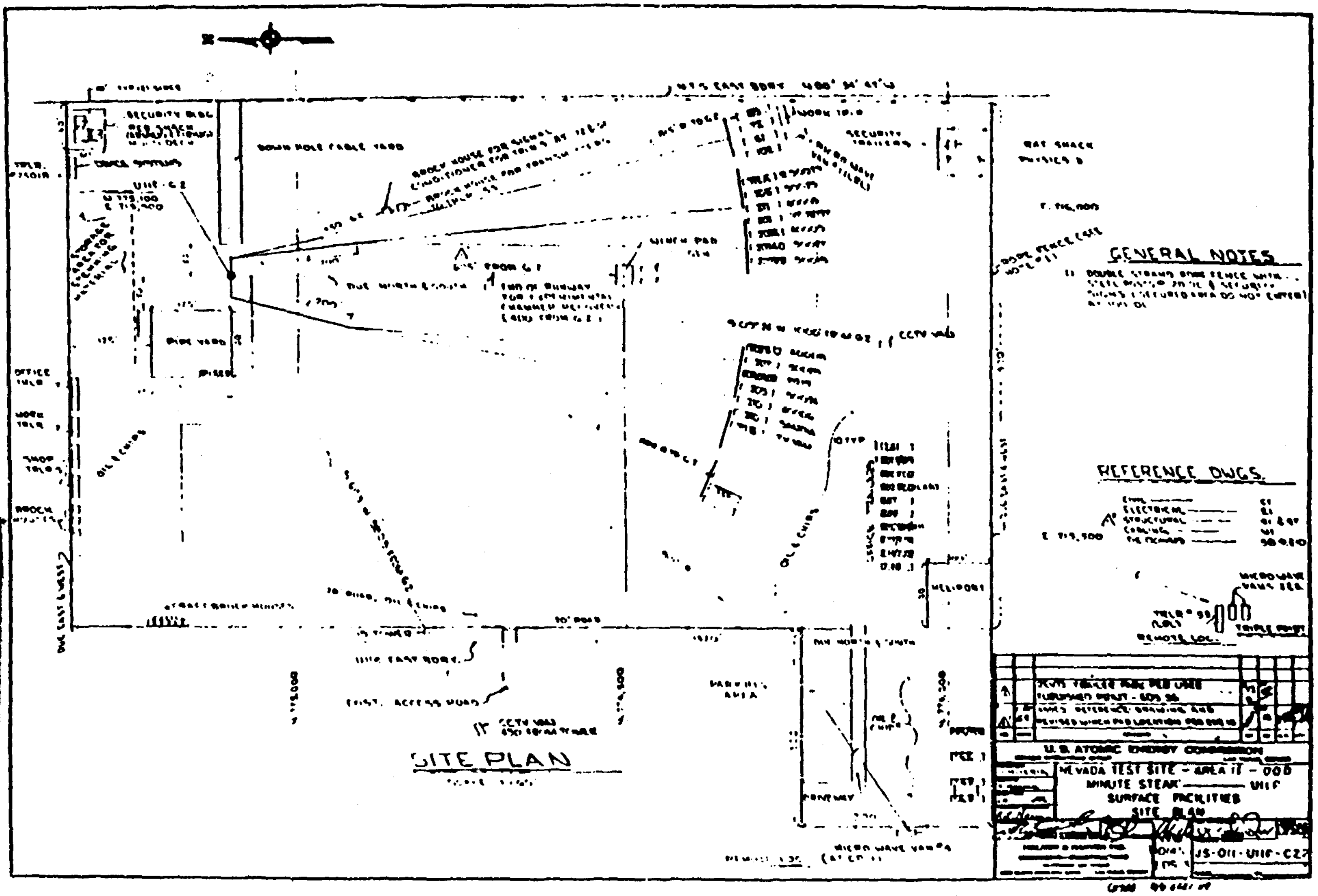
[redacted] [redacted]



[redacted]

Figure 2.4 [redacted]. --MINUTE STEAK trailer park showing locations of project instrumentation trailers [redacted]

[redacted] [redacted]

Figure 2.5 [redacted]—Aerial view of trailer park (NTS photo 152-02-NTS-69)

[redacted]

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[redacted]

[redacted]

2.4.1 [redacted]

[redacted]

There were nine designated stations in the exposure room, and the fluence at each station is listed in table 2.2. Figure 2.7 shows the isofluence lines in relation to the scatterer. Figure 2.8 illustrates the manner in which the experiments were placed on an isofluence line at a particular station.

2.4.2 [redacted] Scatterer.

[redacted]

Figure 2.9 shows the dimensions of the scatterer, and figure 2.10 is a reproduction of the manufacturer's chemical analysis.

2.4.3 [redacted] Experiment Configuration.

[redacted]

[redacted]

[redacted]

TABLE 2.2 [redacted] --Fluence at each station in the exposure room [redacted]

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

[redacted]

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TABLE 2.3 [redacted]--Area used at each station

Station	Area (ft^2)
1	7.5
3	18.0
4a	37.4
4b	18.0
4c	17.4
5a	8.5
5b	21.5
6	6.9
7	3.0
	138.2

Page 27-30 deleted

[redacted]

CHAPTER 3

TEST PROGRAM

[redacted] There were 19 projects on MINUTE STEAK, encompassing 41 experiments. Table 3.1 lists the experiments by project number and their general objective as related to the four test objectives given in section 1.1. Four of the experiments were major experiments in terms of space and cost. These were 2.01, 2.02, 2.08, and 2.09. Table 3.2 lists the percent of the total exposure area used by each project.

3.1 [redacted] SYSTEM RELATED EXPERIMENTS.

[redacted]

[redacted]

[redacted]

[redacted]

TABLE 3.1 [redacted]. --MINUTE STEAK experiments [redacted]

Project	Objective	Type	Agency
2.01a	System	Circuits and Components	SSPO/MIT (IL)
2.01b	System	Semiconductor	SSPO/LMSC
2.02a	System	Semiconductor	SAMSO/GGA
2.02b	System	Circuits	SAMSO/AUTO
2.02c	System	Materials and Components	SAMSO/AUTO
2.03	System	PBPS Engine	SAMSO/AFRPL
2.04a	Hardening	Semiconductor	DASA/AFWL
2.04b	Hardening	Semiconductor	DASA/AFCRL
2.04c	Hardening	Semiconductor	SAMSO/AUTO
2.05	Interaction	Magnetic Materials	DASA/NOL
2.06	Diagnostic	Ferroelectric Measurement (Developmental)	DASA/NEL
2.07a	Interaction	Internal EMP	DASA/HDL
2.07b	System	Internal EMP	DASA/HDL
2.08a	Hardening	Semiconductor	DASA/HDL
2.08b	System	Semiconductor	DASA/HDL
2.09a	Hardening	Semiconductor	DASA/GGA
2.09b	Interaction	Magnetic Materials	DASA/GGA
2.09c	Hardening	Semiconductor	DASA/GGA
2.09d	Hardening	Semiconductor	DASA/GGA
2.10	System	Circuits	SAMSO/MIT (LL)
2.11	Hardening	Circuits	DASA/SPERRY
2.12	Interaction	Materials	DASA/AFRPL
2.13	Diagnostic	Bent Crystal, Passive Determinations	DASA/NRL
2.14	Diagnostic	Passive Neutron and Gamma Measurements	DASA/NEL
2.15	Diagnostic	Thermoluminescent Detector	DASA/NRDL*

*Now at NOL.

[redacted]

[redacted]

[redacted]

TABLE 3.1 [redacted]. --(Continued)

Project	Objective	Type	Agency
2.16	Diagnostic	Passive Determinations in Scattered and Direct Beams	DASA/MRC
2.20a	Diagnostic	Direct Beam Measurements	DASA/LRL
2.20b	Diagnostic	Scattered Environment Measurements	DASA/LRL
2.20c	Diagnostic	Readiness Program	LRL
2.20d	Interaction	Internal EMP	LRL
2.20e	Interaction	EMP	LRL
2.40a	System	Semiconductor	SANDIA
2.40b	Hardening	Component	SANDIA
2.40c	Diagnostic	Readiness Program	SANDIA
2.40d	Interaction	Internal EMP	SANDIA
2.40e	Hardening	Component	SANDIA
2.40f	Interaction	Component	SANDIA
2.40g	Interaction	EMP	SANDIA
9.11a	Diagnostic	LOS Pipe	DASA/EG&G
9.11b	Diagnostic	TV Coverage	DASA/EG&G
9.11c	Diagnostic	Air Shock	DASA/EG&G

[redacted]

[redacted]

TABLE 3.2 [redacted] --Percent of exposure area used by each project [redacted]

Project	Area (percent)
2.01	14.16
2.02	22.49
2.03	0.34
2.04	3.09
2.05	2.16
2.06	0.40
2.07	7.08
2.08	19.71
2.09	17.98
2.10	3.02
2.11	0.27
2.12	0.96
2.13	0.01
2.15	0.11
2.16	0.27
2.20	2.48
2.40	5.44
9.11	0.03
	100.00

[redacted]

measured data with theoretical calculations. The reentry system radar jammers were tested for hardness to projected threat levels.

3.2 ([redacted] HARDENING EXPERIMENTS [redacted] The hardening experiments consisted mostly of semiconductor tests. [redacted] of data were then compared to show failures caused by radiation effects as opposed to handling and shock damage. The magnitude of the effort can be appreciated when it is considered that close to 300,000 continuity paths were monitored and recorded within 50 milliseconds after T_0.

3.3 [redacted] INTERACTION EXPERIMENTS.

[redacted]

[redacted]

measurements made on this type material. The external EMP measurements were made outside the mobile tower.

3.4 [redacted] DIAGNOSTIC EXPERIMENTS.

[redacted]

3.5 [redacted] TIMING AND FIRING. Timing, firing, and monitoring functions were provided remotely on hard wire pairs from the command post several miles away to a timing trailer in the trailer park. These timing signals were fanned out from the timing trailer to the instrumentation trailers, the mobile tower, and the

[redacted]

device. These signals were used to turn on equipment, open camera shutters, start tape recorders, and various other experimental and device functions. Table 3.3 lists the EG&G timing signals used in MINUTE STEAK.

3.6 [redacted] MONITOR AND HOLD SYSTEM.

All the active experiments were monitored at the Control Point for catastrophic failure prior to the shot. Generally, each experiment had a power monitor light and a trailer temperature monitor light. These were actively monitored from the time the experimenters left the park until event time. Also, monitor lights were used for the closure system, pipe vacuum, tower winch power, and critical device functions. If an experiment indicated a failure prior to shot time, a hold could be initiated, the problem resolved, and the countdown then continued. All experiments could survive a holddown to -5 seconds. If a hold came after -5 seconds, some small percentage of data might have been lost. The hold was accomplished by activating a relay with which the experimenters could shut down tape recorders and turn off equipment. Holds were practiced during the dry runs.

An indication from the monitor system that an experiment had lost power did not automatically result in a reentry. In a test of this nature, where large numbers of instruments are used in the field, delays can easily result in the loss of additional equipment. Therefore, the loss of one experiment must be weighed against the possible loss of more experiments and postponement of the test. Also, during the countdown, a point of no return is reached, after which the device must be fired within a given time or the yield may degrade. Therefore, it is mandatory that the percent degradation of the total effort be known when any one experiment indicates improper operation. Table 3.4 lists the weights of each project and shows the percent active and passive. The percent of the active data recorded on film is also important in the event of excessive radioactive release. The weighing of the experiments is arbitrary and takes into consideration their relevance, cost, and difficulty in being repeated.

Another contingency planned for was an accelerated countdown. In the event of an accelerated countdown, as much real time as possible would be given, up to 15 seconds. This was to allow tape recorders to get up to speed, camera shutters to open, and equipment to warm up. All experiments could survive an accelerated countdown to -15 seconds. Data return would degrade increasingly [redacted]

[redacted] [redacted]

TABLE 3.3 [redacted] **--Timing signals used in MINUTE STEAK** [redacted]

-15 minutes	-30 seconds	-100 milliseconds
-10 minutes	-15 seconds	- 40 milliseconds
- 5 minutes	-10 seconds	
- 4 minutes	- 5 seconds	
- 3 minutes	- 3 seconds	
- 2 minutes	- 2 seconds	
- 1 minute	- 1 second	

[redacted]

TABLE 3.4 [redacted]--Weight of each project in relation to the total effort [redacted]

Project	Weight	% Active	% Active of all Experiments	% Film *
2.01a	0.06	95	5.7	0
2.01b	0.06	20	1.2	0
2.02a	0.06	50	3.0	0
2.02b	0.14	95	13.3	0
2.02c	0.02	50	1.0	0
2.03	0.02	100	2.0	0
2.05	0.05	30	1.5	0.5
2.06	0.02	100	2.0	2.0
2.07	0.05	100	5.0	5.0
2.08/2.04	0.13	50	6.5	0
2.09	0.11	60	6.6	2.5
2.10	0.03	50	1.5	0.5
2.11	0.02	95	1.9	1.0
2.12	0.01	0	0	0
2.13	0.02	50	1.0	2.0
2.14	0.01	0	0	0
2.15	0.01	0	0	0
2.16	0.03	0	0	0
2.20a & b	0.05	50	2.5	0
2.20	0.04	100	2.0	0.5
2.40	0.06	50	3.0	0.5
	1.00		59.7	14.5

*Percent of all active data.

[redacted]

as the real time was decreased below 15 seconds. An accelerated countdown to 0 time was impossible because of device considerations, which meant that in no case would all the active data be lost.

[redacted]

[redacted] [redacted]

CHAPTER 4

RESULTS

[redacted] The MINUTE STEAK Event took place on 12 September 1969 at 1100 hours. The countdown went smoothly until -59.3 seconds, at which time there was a hold. This was prompted when the LLL (formerly LRL) microwave van monitor light went out indicating the microwave link carrying diagnostics had failed. A hold at this time did not cause concern since holds after -1 minute had been successfully practiced during dry runs. After approximately 1 minute, the light unexplainably came back on, and the countdown was resumed. All monitor lights were on at T_0 except two LLL tape recorder monitor lights. This indicated that two of the LLL six-tape recorders were not up to proper speed. The redundancy of the LLL system, however, precluded the loss of any data. At +10 seconds, the mobile tower pull winches were started, and at +2 minutes and 39 seconds the tower was at the prescribed 300-foot mark, well outside of the predicted crater radius.

[redacted] All closure system monitors indicated proper operation, and containment was good until ground collapse at +23 minutes. At this time there was some leakage which continued off and on until D + 1 day but did not affect any of the experiments. [redacted] No activation was recorded off the test site at any time during or after leakage. [redacted] Figure 4.1 was taken by a high-speed camera (1,000 frames/sec) located about 800 feet south of ground zero. This picture shows air ionization at T_0 and was obtained by chance since the ratio of open shutter time to closed shutter time is very small. Reentry was started on schedule at H + 1 hour and proceeded smoothly.

---

*Calcium-sulphate in a water-base solution.

[redacted]

Page 42 deleted

[redacted] The caldera 245 feet in diameter and 17 feet deep formed at +23 minutes (figure 4.2). There was consistent nonuniformity in the crush of the trailer supports which indicated a transverse ground shock wave (note figure 4.3). The ground shock caused loss of power in three experiments at about +1 second, but very little data were lost. The projects that lost power were: 2.03, the control panel inside the trailer came off the wall; 2.10, the conduits inside the trailer were torn loose and a power relay opened; 9.11a and c, the voltage regulator came off its supports on the generator. One of the two backup generators for the mobile tower winches was found to be off after the test, but the reason why it was off is unknown.

[redacted]

4.1 [redacted] DIAGNOSTIC RESULTS.

4.1.1 [redacted] Project 2.20a and b (LLL), Active MINUTE STEAK Diagnostics.

[redacted] To accomplish this, several types of detectors were used. [redacted]

The reaction history measurement gave an interval time [redacted]

[redacted]

Figure 4.2 [redacted]--Caldera which formed at ~ T + 23 minutes (NTS photo 168-27-NTS-69) [redacted].

[redacted]

[redacted]

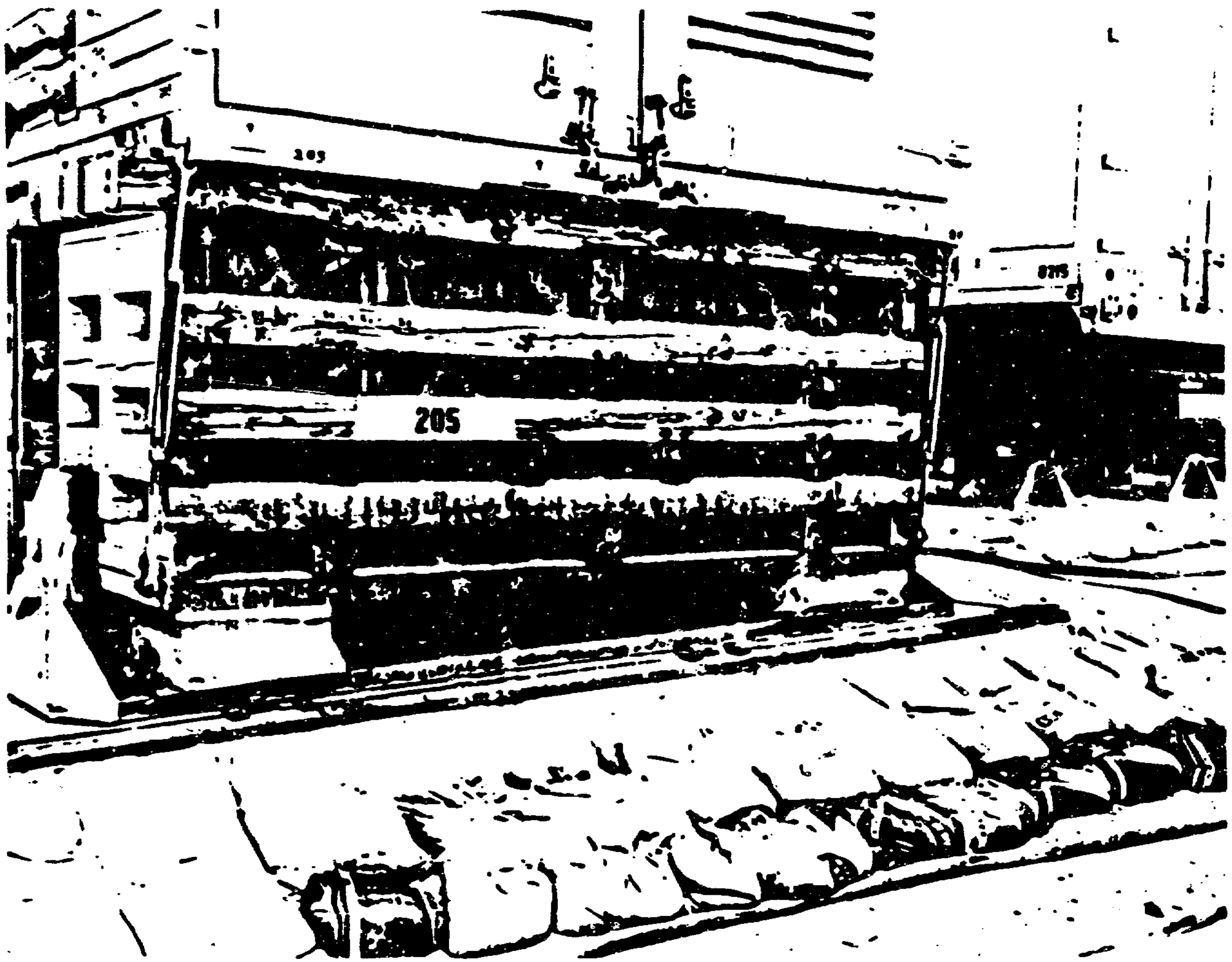

Figure 4.3 [redacted]--Illustration of nonuniform crush of instrumentation shock mounting material (NTS photo 168-21-NTS-69) [redacted].

[redacted]

Pages 46-~~4~~51 have been deleted

[redacted]

TABLE 4.1 [redacted]. --Filter pairs used in MRC spectrum dosimeters [redacted]

[redacted]

TABLE 4.2 [redacted] --Fluence ratios at various angles [redacted]

Angle	Fluence $\left(\frac{\text{Measured}}{\text{Expected}}\right)$
+14°	0.92
+14°	0.92
0°	0.95
0°	0.95
-25°	1.00
-31°	1.10
-55°	1.23

[redacted]

[redacted]

The picture taken with the pinhole camera is shown in figure 4.9. The camera was on the floor looking up at the scatterer.

4.1.3 [redacted]

Pages 54-61 deleted

[redacted]

4.1.8 [redacted] Project 2.20c, High-Altitude Physics.

[redacted], a high-altitude diagnostic package designed for the readiness program.

The high-altitude package consisted of four types of detectors:

(1) ionization chambers,

(2) thermopiles,

(3) fluor-photodiodes, and

(4) resistive thermometer calorimeters.

Also in the package was a simulated front end of a 13-inch rocket payload approximately 100 inches long and weighing 275 pounds, containing electronics, a tape recorder, telemetry transmitters, and power supplies. Three different systems redundantly handled some of the detector outputs of the simulated payload. The data were telemetered to a manned receiving station, digitized and stored in a permanent diode-matrix memory, and digitized and stored on magnetic tape.

The repetitively sampled digital system worked well. The diode-matrix memory was prematurely activated and did not record any data. Also, the umbilical separation mechanism and the control cables remained connected, which acted as an antenna. The telemetry system worked, and the payload electronics recovered in a few hundred microseconds. Data were not obtained from the ionization chamber by fluor-photodiodes because of saturated signals. The thermopiles and calorimeters operated as expected, and the agreement on the measured flux was within calibration accuracy. The objectives were about 50 percent accomplished.

4.1.9 [redacted] Project 2.40c, Readiness Program Debris Analyzer. The objective was to determine the magnitude and duration o[redacted]n a nuclear readiness program debris analyzer.

The arrival time of the debris measured in high-altitude nuclear tests is about 100 msec. Because of the high electrostatic field (about 6 kV/cm) between the analyzer plates, a long-duration, plasma-like discharge caused by radiation could cause a voltage breakdown which would affect the measurements. The test item was placed at th[redacted]ion; however, it is a long package, and the

[redacted]

[redacted]

fluence between the plates was less than predicted, probably abo [redacted] It was shown that for this fluence and debris-analyzer configuration the electric field did not cause breakdown; thus, in an actual high-altitude test, when the debris arrived, it would be properly analyzed.

4.1.10 [redacted] Project 9.11a, b, and c, Pipe Diagnostics, TV Coverage and Shock.

The LOS pipe and closure system have been described in an earlier chapter. The objective of 9.11a was to record on magnetic tape the closure times of debris containment devices, time of shock arrival, long-term pressure measurements, ground displacement, and ground motion.

[redacted]

4.2 [redacted] SYSTEM EXPERIMENTS.

4.2.1 [redacted] Project 2.01a, Poseidon Guidance System Components Test.

[redacted]

Pages 64-65 are deleted

[redacted]

in the ancillary equipment which prematurely turned power off. The passive vidicon tubes were recovered; one had the glass envelope broken during recovery. The other two operated normally. Lifetime tests were planned.

The magnetic core experiment was composed of 10 tactical configured six-bit registers and 10 nontactical configured six-bit registers. The nontactical configurations included open circuit, diodes only, capacitors only, shorted bits, and shorted interconnects. The cores were 170-mil tape wound, 1 mil permalloy on stainless steel bobbins.

The dose received on the test was abou [redacted] Of the 120 cores in the experiment, eight bits were changed, showing no particular pattern with respect to circuitry or orientation. Some partial switching was observed. There is some reason to believe that the bits that were switched may represent errors in the experiment, so the results are inconclusive.

Two sets of three optical elements of the Cassegrain telescope associated with the vidicon were exposed. Acceptance test procedures were performed before and after. No physical damage and negligible optical degradation were observed.

4.2.2 [redacted] Project 2.01b, Poseidon Semiconductor Components.

The objectives were to:

[redacted]

(2) study the metallization damage phenomena which was observed on certain parts tested in MILK SHAKE,

(3) study the degradation of electrical parameters (β, I_{CBO}) in Poseidon transistors,

(4) study IEMP in Poseidon cables, and

(5) evaluate the uses of solder in the Poseidon missile.

The following four changes were made in the construction process of transistors:

(1) 1-mil aluminum wire was welded to the post and the wire attachment points at the binding post were coated with resin,

 [redacted]

[redacted]

[redacted] [redacted]

(2) the deformation of wire at the binding post was limited to between 135 and 250 percent and a no-void criteria was maintained in the die-to-header attachment with ~10 percent visible voids on any side of the die,

(3) ultrasonically bonded, aluminum 1-mil wire was used to the wire-to-die attachment, and

(4) a performless die-to-header attachment was used.

Six changes were made in the integrated circuit construction:

(1) a no-void criteria was maintained at the die attach,

(2) gold thickness in the die attach was controlled,

(3) gold thickness on the lead-in ribbon was controlled,

(4) 1-mil aluminum wire with controlled impurities was used,

(5) ultrasonic bonds were used at the die and lead-in ribbon, and

(6) fishtails or double bonds were not allowed.

A total of 2,355 of these devices were passively tested. They were checked for continuity a few hours before T_0 and again a few hours after T_0. To obtain phenomenology data on die-to-header bond failures and metallization failures, two types of test samples were irradiated. These were functional types of integrated circuits exposed with power applied and a silicon die of special design to separate certain variables; i.e., metallization geometry, contact area, large P-N junction, bias, and package material. Active-bias integrated circuits were exposed to dose [redacted]

Simplified geometry devices were used to determine metallization burnout. Some of the devices were biased during the test

Eighteen NPN transistors were measured for changes in current gain at deposition levels o[redacted]. Recovery of the gain degradation was recorded on an oscillograph.

Both active and passive experiments were made on shielded wire and flat cable. The voltages were recorded on oscilloscopes in the active tests, and peak detectors and magnetic spheres were used to obtain data on the passive samples. The voltage outputs from a Compton diode and a capacitor were also recorded.

The use of solder on multilayer circuit boards and cable shielding repairs was investigated by exposing samples of these items to surface dose [redacted]

[redacted]

[redacted]

Results were obtained for all the objectives. There were no semiconductor device failures out of approximately 1,455 devices [redacted] there were about 42 failures out of 374 integrated circuits and no failures out of 448 bipolar devices. The metallization damage observed was of the microcrack variety. The most important information that can be obtained from this portion of the test is the verification that the microcracks did occur at zero time, implying that a radiation-induced stress caused the stripe discontinuity. Gain degradation was recorded on all 18 C3 transistors. In general, the degradation obtained in MINUTE STEAK is more severe than that in Hermes. In an effort to resolve the differences, further calculations are being made to determine if secondary electron emission from the transistor-can in MINUTE STEAK contributes significantly to the total dose at the chip (secondary emission was not included in pretest calculations). Good results were obtained in the IEMP cable experiment, and table 4.6 lists some of the results as compared to predictions.

The solder experiment demonstrated that even though there was some spall and spatter, solder use would probably be permissible in the parts tested.

All of the project objectives were attained in this test.

4.2.3 [redacted] Project 2.02a [redacted]

The objectives were to:

[redacted] of Block III and IV Minuteman III parts against bond damage and metallization burnout,

[redacted]

(3) obtain baseline data to use in establishing a hardness assurance program for Minuteman III piece parts.

Three systems worth of semiconductor piece parts (about 26,000) were tested for X-ray-induced damage. One system was exposed at criterio[redacted] one at two times criterion, and one at five times criterion. Data on all parts were recorded immediately (i.e., milliseconds) before and after T_0 by means of an elaborate commutation system. This was done to assure that any damage noted was the result of radiation and not of ground shock or handling.

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No radiation-induced lead bond failures were found nor were any radiation-induced metallization burnouts observed in either new MINUTE STEAK parts or reexposed MILK SHAKE parts. A total of 45 possible other failure indications was detected in the screening of data, all in new parts. An analysis indicated that 29 of these potential failures were clearly not the result of th[redacted]d, therefore, were outside the scope of the test objectives of this experiment.

The remaining 16 possible zero-time failures were further analyzed, and 12 were found to be the result of artifacts of manufacture of the mounting assemblies: open solder joints, faulty connector engagement, malfunctioning subcommutator driver, open board circuit, and intermittent circuit-isolation diode operation. Four of these 45 failures were possible radiation-induced failures.

The commutator data are ambiguous on the time of failure of these four malfunctioning parts. One failure was caused by an external lead break; the others are more subtle effects at the semiconductor chip. From the standpoint of overall systems implications, the possibility of such radiation-induced effects invites further inquiry.

4.2.4 [redacted] Project 2.02b, Minuteman III Computer Test.

The objective was to verify the hardness of engineering model Minuteman III computers and provide timely inputs to Minuteman III production computer design hardness analysis.

This experiment was the first test of an operating Minuteman computer in a total nuclear device environment. Two operating D37D-1 computers were tested. One was exposed at approximately [redacted] Shielding was adjusted so that the depth-dose profile was a worst case test. The computers were operated in a special 60-msec program which repeatedly exercised as much logic and circuitry as possible and allowed testing of critical in-flight functions. Figure 4.12 shows the equipment and instrumentation layout.

[redacted] [redacted]

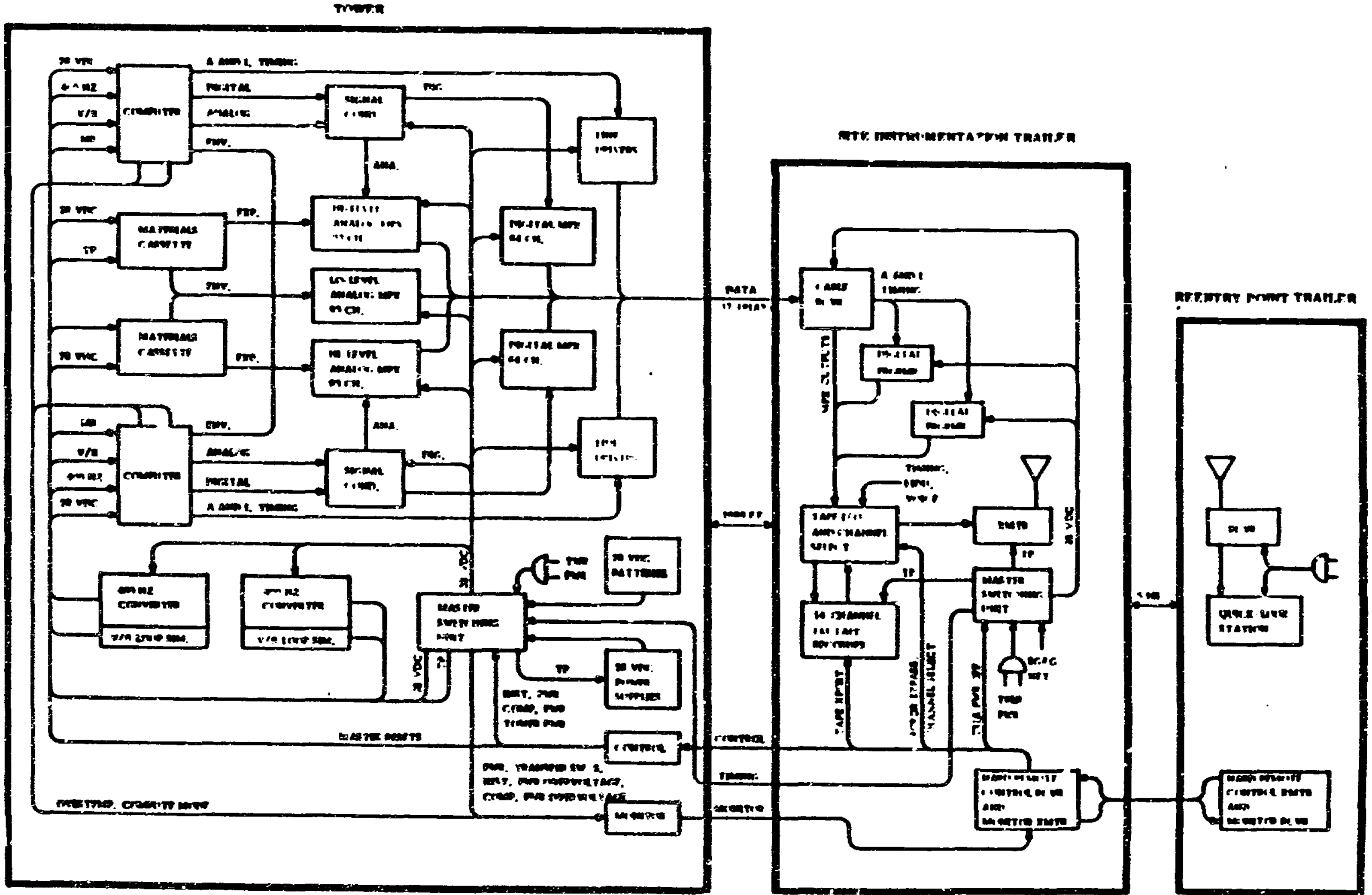

Figure 4.12 [redacted]--Equipment and instrumentation layout for computer test [redacted]

The D37D-1 computer at the criterion station operated correctly through the test event and incurred no significant radiation damage. The transient malfunction at T + 26.5 seconds was not related to the radiation environment. Average values of the diagnostics indicate that the test radiation environment equaled or exceeded the Minuteman III radiation criteria.

The D37D-1 computer at the five times criterion station exhibited a transient malfunction shortly after T_0. The analyses of the radiation malfunction response of the computers indicate that delayed gamma radiation prevented the setting of flip-flops critical to computer recovery from circumvention. The computer suffered no permanent radiation damage.

No change in the D37D design is required to remove this extended radiation pulse malfunction mode. Advanced design D37D computers have an all pulse-width (dc coupled) hostile environment detector which prevents setting critical flip-flops before radiation levels are below the computer vulnerability threshold. This experiment accomplished all its objectives.

4.2.5 [redacted] Project 2.02c, Guidance and Control Materials Radiation Field Test.

The objectives were to determi[redacted] selected samples of materials and components from the Minuteman III Guidance and Control (G&C) system to verify previous analysis and to test components not amenable to analysis or laboratory testing.

Six items were tested at both th[redacted]ations. These were:

(1) a silver-zinc battery which provides 28 volts dc for in-flight operation of the Flight Control Systems, the NS20MGS, and the Reentry System,

(2) a Critical Leads Disconnect Switch,

(3) Gyro-Stabilized Platform and Fill Valve Samples,

(4) Material Samples from Flight Control Hardware End Items,

(5) a Diode Block Assembly, and

(6) [redacted]

The items were exposed so that the surface dose comparison of a worst-case criterion and the dose received at MINUTE STEAK were within a few percent. Some of the possible effects looked for were glass cracks in the battery, shorted contacts in the switch, bond failures in the housing samples, blowoff of material samples, delamination in the diode block assembly, and permeability decreases in the Hipernom samples. Some of the samples were active during the test.

The experiment objective was met. All of the test items functionally survived at the low and high stations. [redacted]

Battery. The low and high station batteries survived the test environment. Test data confirm survivability of the battery in the entire criteria X-ray spectral range [redacted] except for the terminal feedthroughs and the steel case.

Critical Leads Disconnect Switch. The low and high station switches survived the test environment. Electrical characteristics remained within specification after exposure. Test data confirm survivability of the switch in criteria environments [redacted]

GSP Housing. The GSP housing samples with tantalum scratch repair patches survived the test; that is, the observed material effects would not significantly impact GSP operation. The damage to the gold finish would still allow proper thermal control in the GSP. The fact that the aluminum to tantalum epoxy bond failed in the high station samples is not significant, since these bonds have been replaced in the Minuteman III design by a strongly radiation-resistant titanium welded configuration.

Flight Control Materials. The flight control samples survived the high and low station environments. A negligible amount of surface material was lost. Test data confirm survivability of the flight control shields simulated by the test samples in the [redacted] criteria environment range.

Diode Block. The low and high station diode blocks survived the test environments. Electrical characteristics remained well within specification after exposure.

Hipernom Cable Shields. The Hipernom cables and washers survived at the high and low stations, and rf attenuation capability remained within specifications. Survivability of EMP shielding capability is predicted for criteria environment spectr[redacted] Radiation environment contribution, if any, to

[redacted]

the degradation in connector rf shielding effectiveness could not be separated from the oven thermal environment contribution.

4.2.6 [redacted] Project 2.03, [redacted] Engine.

The objective was to determine the survivability of an operating 23-pound thrust pitch and yaw control engine, used in the Post Boost Propulsion System of Minuteman, [redacted]

The exhaust nozzle and throat operate at 1,600° F after 3 to 5 seconds of burning time. Spalling or cracking, caused [redacted] deposition at this time, could cause failure. Theoretical analysis showed that the margin of safety would be significantly reduced by th[redacted] eposition. There were 0.28 pound of fuel, monomethyl hydrazine and 0.40 pound of oxidizer, nitrogen tetroxide, which gave 6 seconds (-3 seconds to +3 seconds) of burn time. Helium was used for pressurization and as a purge. Data, recorded on tape, were obtained on the pressure in the chamber and the fuel and oxidizer. Analysis of the operating engine's chamber pressure trace and visual inspection of the engine's nozzle and throat indicate that no damage occurred from absorption of [redacted] Ground shock caused loss of power at approximately +1 second but caused no loss of data. All the project objectives were accomplished.

4.2.7 [redacted] Project 2.07b, Internal EMP.

The objectives were to:

(1) measure the currents in principal cables and the internal magnetic field in a mockup section of the third stage of the Spartan missile, and

(2) measure the photo and Compton electron current densities emitted from both shielded and unshielded sections of the skin of the Spartan missile.

The Spartan model was scaled down to 1/2-linear dimensions so that the model length to induced electromagnetic wavelength ratio would simulate the actual threat case. Five wires in the harnesses were actively monitored along with a test loop and a noise cable. Several wires were passively monitored with Sandia Corporation magnetic transfluxors. The H field in the mockup was measured with Lockheed Research Corporation magnetic spheres. Three diode detectors had simulated Spartan skin as a front surface. These were combinations of tin and aluminum, and the vacuum ranged from 0.01 to 10m Torr. Pulse shapes

[redacted]

[redacted]

were faithfully recorded on fast oscilloscopes. These items were at th[redacted]

Signals over [redacted]d of duration greater th[redacted] were observed on all cables monitored in the Spartan model with the exception of the noise cable and the cable attached to the Spartan S-band antenna coaxial line. The noise cable had a [redacted] Sweep times were too short to record the return of the signal to the base line. The H fields were [redacted] in the unshielded section of the model and 15 to 20 oersteds in the shielded section of the model. [redacted] These were close to predicted. All the objectives of this experiment were accomplished. Figure 4.13 illustrates one of the detector outputs at T_0.

4.2.8 [redacted] Project 2.08b, Safeguard System Components.

The objectives were to determine the probability of failure curve of the most widely used Safeguard system semiconductor components and evaluate the effectiveness of a screening procedure for metallization burnout.

A total of 5,500 devices were exposed at five levels ranging fro[redacted]ith expected failure fractions of 0.001 to 0.90. Of these, 6,000 went through the metallization screen consisting of a 5-second, 700-mamp current pulse to each chip. There were about 1 percent metallization dropouts during the screening test. Each device was tested before and after the event but exposed passively. These were standard gold technology construction.

The observed failure fractions ranged from 0.07 to 0.93, very close to predicted. No die-bond failures were observed, even at[redacted]evel where some would be expected, indicating that a superior die-bonding procedure had been obtained. Also, no metallization burnouts were observed indicating that a good metallization technique had been obtained. All failures but one were due to gold ball-bond lift-offs. Since this bond is now established as the weakest part of the structure with regard to thermomechanical considerations, improvements in the design should be made.

Failure analysis revealed that only about 30 to 50 percent of the ball was bonded, the remainder was simply resting on the SiO_2. Among the possible

[redacted]

[redacted]

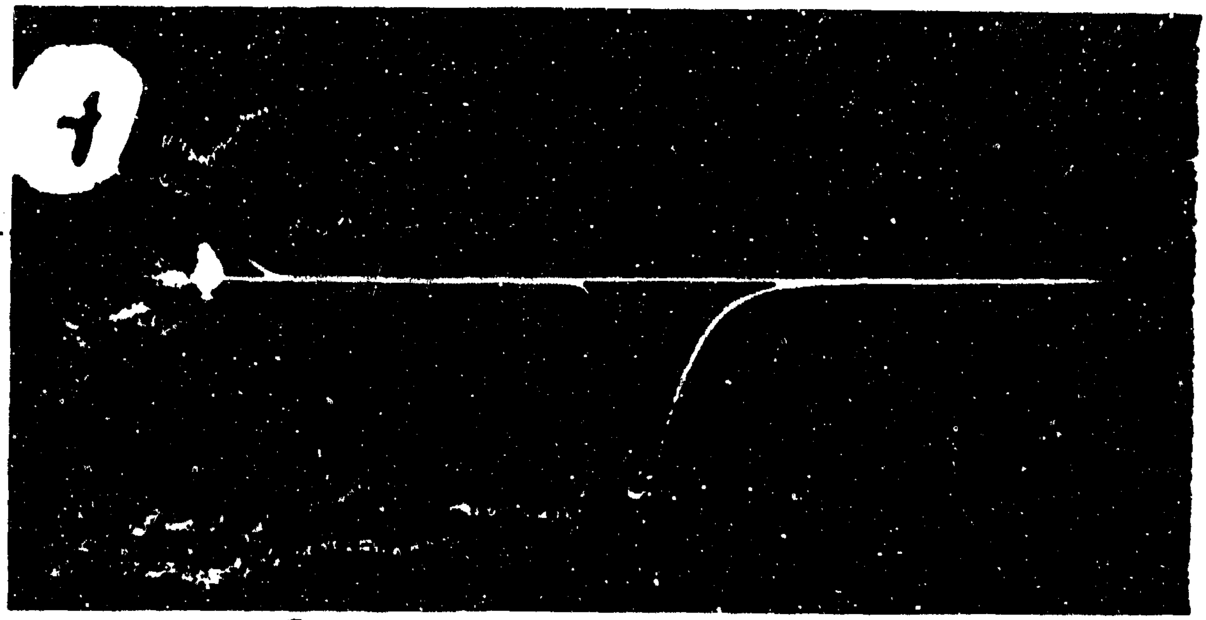

Figure 4.13 [redacted]--Internal EMP detector output at $\overset{*}{T}_0$, Project 2.07 [redacted]

[redacted]

ways to improve the bonds are the following:

(1) enlarge the bonding pad, and

(2) change to gold metallization.

4.2.[redacted]) Project 2.10, ECM Circuits and Components.

The objective was to determine th[redacted]f jammers in the context of their employment as ICBM penetration aids.

Operating circuits and components were exposed at fluence levels between [redacted]he circuits included transmitter modules, RF amplifiers, noise sources, YIG filters, and oscillators. The components were mostly active and passive (about 300) transistors along with a silver-zinc battery. The primary measurements were of the power and frequency spectrum output. The RF output signals were displayed and recorded from spectrum analyzers and also detected and recorded as dc signals.

At ground shock arrival, about +1 second, power to the instrumentation trailer was cut off and data were lost after this time; however, up to 90 percent of the objectives may still be obtained from analysis of the data obtained. Table 4.7 lists the results obtained on the active circuits.

An overall condensed summary of the passive transistor experiment shows that of the nine types exposed t[redacted]

4.2.10[redacted] Project 2.40a, Mk 3 Semiconductors.

The objectives were to ascertain that failure rates in Mk 3 semiconductors associated wit[redacted]re acceptable[redacted] and to correlate with electron beam tests.

[redacted]

TABLE 4.7 [redacted] --MINUTE STEAK Project 2.10, results obtained from tests of active circuits [redacted]

Station						
Fluence (cal/cm^2)	[redacted]					
Circuit						
MEP Transmitter (potted)	S	S	S			
MEP Transmitter (bare)				S	F	S
MEP Battery	S					
Noise Source-VCO	F			F		
LPP Amplifiers	F	F	S	S	S	S
LEX-1 Modules	F	F	S	F	F	F
LEX-2 Modules	F	S		S	S	
TTB MM1559	S	S	S	S	S	S
TA7344	S	S	S	S	S	S
S1050		F		F	S	S
ADOs	S			S		

S - Survived

F - Failed

 [redacted]

[redacted]

A total of 4,500 transistors and 1,080 integrated circuits were distributed equally at level [redacted] The back of the unit was facing the incident fluence to prevent melting of the Si-Au die attach layer and limit damage from shock effects. Four different capacitor discharge units were also exposed to determine their induced charge losses.

The results of the transistor portion of the semiconductor experiments indicated that there was a significantly large increase in the [redacted] There were 23 catastrophic mechanical failures out of 4,085 transistors. Of the 23 failures, 22 were failures of the 1-mil wire bond at the post. The one unit that failed at the heel of a wire bond at the silicon die exhibited evidence of mishandling. Thus, it is felt that the 22 postbond failures are really the only failures [redacted] Of these 22 transistors that failed, [redacted] Of the 4,085 transistors exposed, 2,700 had the [redacted]

The ICs in MINUTE STEAK failed in the same general manner as the ICs that were exposed to the electron beam environment. These failures included lead bond failures, die fracture, and total delamination of the die from the package.

Four types of energy storage capacitors were exposed in the MINUTE STEAK Event:

(1) ceramic used in the Mk 3, Castor, Sprint, and Spartan;

(2) Bentonite, used in the backup Sprint Capacitor Discharge Unit (CDU);

(3) mica paper as used in the Sprint and Spartan main CDUs; and

(4) Mylar, used as a reference.

The quantitative agreement between predicted and observed charge loss results is good for the mica paper type but poor for the other types. Recent laboratory work with the bentonite type shows such a wide and unpredictable variation in radiation-induced charge loss that, at present, it is meaningless to attempt predictions for this type.

4.3 [redacted] HARDENING EXPERIMENTS [redacted]

4.3.1 [redacted] Project 2.04a, Metallization and Bond Study.

[redacted]

The objectives were to:

(1) verify the Scanning Electron Mirror Microscope (SEMM) as a possible 100 percent semiconductor piece part screen,

(2) test new hardening techniques and processes in a field test environment, and

(3) compare field test data with that obtained in electron beam experiments on metallization burnout failure mechanisms.

Large secondary photocurrents flowing in metallization strips that contain defects can cause burnouts. These defects can be detected with the SEMM and removed during production line quality control. Since the electron beam does not impinge upon the sample, this is a nondestructive screen. The test structure was a modified 2N918 transistor with eight metallization patterns, and three metallization thicknesses were employed. Data were recorded on magnetic tape, and all parts were monitored prior to ground shock arrival. A total of 150 transistors were teste[redacted] New hardening techniques tried were the geometrical dependence of bond failures, beam lead devices, lead wire thickness, beryllia headers, glass frit mounts, epoxy seals, the influence of molybdenum on die attach, and a comparison of Au-(Mo-Au) bonds with Au-Al bonds and Al-Al bonds. These were passive tests.

Thirty-one percent of the transistors at the [redacted] station*. Good data were obtained on cross-sectional area dependence of the burnout with the thicker sections showing less damage. The data from E-beam testing and the posttest analysis indicate that the SEMM does have possibilities as a 100 percent semiconductor screen; however, the present equipment and techniques need to be refined. The geometrical dependence of bond failure study was lost due to the 100 percent failure caused by gold wire and plating vaporization and die attach and chip fractures. There were several damaged devices in the hardening experiment which will allow comparison between various techniques. Approximately 80 percent of the project objectives were accomplished.

[redacted]

 [redacted]

[redacted]

4.3.2 [redacted] Project 2.04b Hardened Power Transistor [redacted]

The objective was to evaluate the measures taken to harden power transistors. These transistors are made with multiple chips and wires, deposited silicon emitter resistors to minimize second breakdown, aluminum contacts and wires, Si-Ge eutectics, and ceramic headers. Forty-five devices were expos [redacted] Twenty of the devices were placed under collector-emmiter bias voltage.

In spite of the fact that there were 88 metallization defects, 20 wire-bond failures, and 1 die-attach failure, all the transistors met electrical specifications after the test. The worst gain degradation was 40 percent with more typical values of 10 to 20 percent. [redacted] eakage currents increased as expected, and breakdown voltages remained the same or increased slightly. Devices with severe metallization damage had essentially the same electrical characteristic degradation as undamaged devices. This is probably due to the multiple emitters present on each chip. Significant damage can occur to the metallization and still allow a large fraction of the device to operate normally. A number of small experiments were also exposed by Project 2.04b. A brief description of the experiment and these results are given below.

Thin-Film Hybrid Materials. The main objective of this experiment was to compare the relative X-ray vulnerability of gold and aluminum based thin film hybrid systems. The results indicate the gold thin film hybrids were completely destroye [redacted] little damage. The aluminum thin film hybrids survived at both stations. The absence of thermomechanical failures [redacted] shows promise for the future use of thin film hybrid structures.

Geometrical Dependence of Bond Failures. The main objective of this experiment was the correlation of field data with laboratory data on a geometrical dependence of lead-wire failures due to constructive interference of thermomechanical shock waves. The field verification of this effect was a failure, as all of the 279 devices failed to withstand the elevated doses attained. Because

[redacted]

there appears to be ample laboratory data in support of the geometrical dependence theory, another attempt at field verification is not recommended.

Beam-Lead Devices. The main objectives of this experiment were:

(1) a quick-look investigation of possib[redacted] problem areas with beam leads, and

(2) the verification of the radiation hardening beam lead technology of the subject circuit.

Eight SG140 integrated circuits (IC) and 11 SG140 beam lead chips were irradiated [redacted] No permanent damage or electrical degradation was observed for the eight SG140 ICs, and the SG140 chips were found to be electrically within specifications where measurements were possible. The only possible failure or degradation observed was the slight increase in resistivity of an ohmic contact of two SG140 chips. The increase in resistivity was small enough to be within the experimental error.

4.3.3 [redacted]) Project 2.04c, Bond-Puller Experiment.

The objectives were to test the following two hypotheses:

(1) Semiconductor device gold-gold wire bond failure at near criterion level [redacted]s due to mechanically defective wire bonds which can be identified by pulling the interconnect wire to some nominal force level, and

(2) The nondestructive pull test screen does not degrade the radiation resistance of good bonds.

Approximately 3,300 Minuteman integrated circuits were exposed to an average deposi[redacted] the ball bond. The majority (2,470) had been screened with a wire puller, while 825 were left as controls.

One device in each group failed due to chip fracture which intersected and opened a metallization strip. [redacted]

4.3.4 [redacted]roject 2.08a, Hardened Transistors.

The objectives were to:

(1) demonstrat[redacted]the higher reliability of a

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[redacted]

4.3.5 [redacted] Project 2.09a, c, and d, [redacted] Semiconductor Devices.

The objectives were:

(Part a) determine failure mechanisms in recently developed technologies,

(Part c) evaluate new hardening techniques, and

(Part d) determine low probability failure data for the MC-833 integrated circuit.

This was primarily a test of advanced [redacted] semiconductor devices. About 12,000 devices were irradiated in the test, including devices

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[redacted]

with intermediate- and low-Z packages, plastic encapsulation, a soft plastic die coating, and flip-chip and beam-lead construction.

Dielectric isolated (DI) diodes and multi-chip (MC) diodes were irradiated at five levels. The DI diodes exhibited a fairly high failure rate, even at low levels. These failures were due to bond failures and metallization burnout. The multiple-chip diodes devices survived very well and show promise as a technique for making extra-hard signal diodes. Again, the AlGe die attachment survived the highest levels. The principal mode of failure for these devices was the fracture of the header. This most likely resulted from the overpressure and filter impact, since these headers were much larger (about twice as long) than the standard package.

Ceramic flatpacks with beryllia header power transistors showed high failure rates[redacted]. Two types of TO-5 power transistors were included in the test. One had a molybdenum insert between the silicon die and the steel header, while the other had the die attached directly to a Kovar header. No failures were observed in the devices without the molybdenum insert while failures were observed in the others. Unexpected failures were observed in devices utilizing the inverted die mounting technique. Plastic encapsulated transistors and operational amplifiers are still being examined. A pulse-length correlation test was also performed. The number of failures was as expected and will be compared to laboratory results.

In Part c, the MC-833 IC was exposed with two different sealants. The Pyroceramic sealant used to hermetically seal the lids failed catastrophically at all the higher levels. Even where the Pyroceramic itself did not fail, shocks were generated in it which propagated to other parts of the device, causing failure.

On the other hand, the devices sealed with the Schultz glass sealant survived the highest two levels [redacted] with only a few lid failures and a few wire failures. Furthermore, no internal damage, such as die attachment failure, die fracture, or wire bond failures, was found in the Schultz-glass-sealed devices.

Part d, the statistical test for the MC-833 integrated circuit was designed to be a proof test at intermediate levels and low failure rates of a super-hard technology. No failures were expected to occur up to or abo[redacted]

[redacted]

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[redacted]

TABLE 4.8 [redacted]--Summary of results for MC-833 statistical test [redacted]

Station	[redacted]	Devices Tested	Devices Failed	Before Shot	Net Failure	Chip Fractures	Open Welds	Other
4a	[redacted]	1512	140	30	110	106	1	3 [a]
4a	[redacted]	870	45	14	31	21	3	7 [b]
5a	[redacted]	798	23	10	13	8	5	
5a	[redacted]	1512	28	15	13		11	2 [c]

(a) Interelectrode shorts--probably a manufacturing defect, since others with similar failures were observed to have occurred before zero time.

(b) Five interelectrode shorts and two broken wires (for comments see text).

(c) Lead broken outside case, probably mechanical damage not associated with radiation.

[redacted]

operated nominally after a period of instability. The output pulse width was at least five times greater than the specified 1.5 msec. The principal anomalies can be traced to the detection circuit and the voltage regulator. The PIN diode in particular experienced a large saturation dose and suffered permanent damage.

The timer unit, with a radiation tolerance based upon the frequency discrimination of permalloy magnetic cores, functioned perfectly during the radiation period with the principal radiation effect observed on the 12-volt regulator as an 18-msec decay transient. Although the circuits did not perform as hoped, the objectives were accomplished.

4.3.7 [redacted] Project 2.40b (SLA), Hardened Neutron Generator Tubes

[redacted] The objective was to test hardened neutron generator tubes for mechanical failure. Mechanical failures of MC-2041 neutron generator tubes were discovered on the CYPRESS Event. Changes were made in the construction and passively tested at Station 1. Six tubes and four tube headers were exposed to [redacted]nd examined for overstressing of the high-voltage ceramic which could result in a fracture at the ceramic and molybdenum plate interface. All the tubes survived, but all the headers failed. This exposure was an overtest of the headers, but the objectives were accomplished. The consistency of the results suggests that the process changes incorporated into these units to eliminate residual stresses were successful.

4.3.8 [redacted] Project 2.40e (SLA), Pulse Power Strain Gage. The objective was to evaluate a fast recovery strain measurement system. This system was designed to recover, in times less than 30 to 40 μsec, the recovery time of present systems. An aluminum tuning fork was prestrained and measured during the test. Large noise signals were observed, and there were no indications of a tuning fork strain signal. The tentative conclusion is that the pulse power supplier failed to supply excitation voltage to the strain gages. The project objective was not obtained.

4.4 [redacted] INTERACTION EXPERIMENTS.

4.4.1 [redacted] Project 2.05, Magnetic Materials.

The objectives of this experiment were to:

(1) investigate the behavior of magnetic materials and memory devices.

[redacted]

(2) investigate the interactions between electrical windings and memory cores, and

(3) determine which magnetic and physical properties significantly affect the hardness of magnetic memory elements[redacted]

The experiment consisted of preset-passive-magnetic memory devices and passive magnetometers in cassettes at Stations 1, 3a, and 6. The cassette at Station 3a also contained active magnetometers and calorimetric dosimetry as well as 60 actively monitored preset permalloy and ferrite-magnetic memory devices in which voltages induced on the windings were to be monitored.

Both active and passive magnetic field measurements indicated that very complex magnetic fields were generated within the Station 3a and Station 6 cassettes. The active measurements showed oscillating fields. The passive spherical magnetometers indicated the magnetic fields changed in both amplitude and direction over the surfaces of the cores. As the spherical magnetometers provide poor indications of oscillating fields, their results were regarded as minimum field strength indications only, and thus the correlation of effects with radiation-induced magnetic fields is only qualitative.

The ferrite cores without windings provided data on the susceptibility of information stored in magnetic devices to nuclear radiation. Twenty types of cores were exposed in groups of 10 to 20 to seven different radiation levels. The reduction in residual magnetic flux in the cores varie[redacted]oss in these cores tracked very well with magnetostriction and coercivity as is predicted by magnetoacoustic theory.

Actively monitored preset cores produced output signals at radiation arrival time which lasted approximately 1 microsecond which is about the acoustic transit time of the cores. The energy in the output signals was proportional to the magnetostriction of the cores and agreed with measurements of flux lost in the cores.

The general conclusions of this experiment ar[redacted]in the [redacted]magnetic cores will produce flux loss through magnetoacoustic interactions; the amount of flux loss is determined by the peak-induced

[redacted]

strain, the magnetostriction and the coercivity of the core; the amount of flux loss will be greater for cores with winds; and that pulsed magnetic fields external to the core will interact synergistically with magnetoacoustically produced internal fields to increase the amount of flux loss.

4.4.2 [redacted]

The objective was to measure the effects of air pressure on the transmitted photoelectric and Compton currents in enclosures.

Three diode detectors, at various pressures, were used to measure the magnitude of the current pulse. These had 40-mil-thick aluminum faces and air pressures of 13 Torr, 44 Torr, and 250 Torr. Equalizers were used for each signal cable and the results displayed on fast oscilloscopes with 30 nsec sweep times. The peak voltages were 1,815 volts, low pressure, 1,235 volts at the medium pressure, and 1,008 volts at the higher pressure. These results agreed with prediction. [redacted] accomplished.

4.4.3 [redacted]

The objective was to obtain data on the effects of [redacted] on magnetic memory components. Four types of cores and two types of plated wire were tested. These were a permalloy-type core wound on a stainless steel bobbin, a permalloy-type core wound on a ceramic bobbin, a ferrite core composed of a lithium ferrite, a ferrite core composed of a manganese ferrite, a Honeywell plated wire module, and an IBM plated wire module. Active data were obtained using oscilloscopes, a camera with a high speed film transport, and an FM tape recorder. There were also passive samples for comparison.

Permalloy tape-wound cores on stainless steel bobbins switched state when subjected to an enhanced electron emission. [redacted]

Radiation-induced switching results from thermomechanical shock and an induced concentric field. The direction of the induced field is important in core switching. Much of the confused data on core switching results from the fact that the direction of the IEMP field is unknown and, hence, the direction of coupling is unknown.

The tape-wound permalloy cores on ceramic bobbins showed permanent damage. The posttest read pulse was reduced in amplitude, as well as the base width being lengthened. Passive cores of this type, exposed in the same environment and with wires through them, showed a gross change in the shape of the hysteresis loop after the test. The level at which a permanent change in the magnetic characteristics occurs i[redacted] This same approximate level holds for permanent effects on plated-wire elements also. This is approximately 1/3 the level at which physical damage is observed to occur. No switches were observed in the active data even at the high level; however, the thermomechanical shock was much less because of the ceramic bobbin. The passive cores exposed at high levels and permanently damaged did show state reversal.

The data on the ferrite cores are somewhat less conclusive; however, they still indicate that IEMP influences core response to a radiation field. The more sensitive of the two types tested seemed to be the lithium ferrite cores with the largest polycrystalline magnetostriction.

The Honeywell closed easy axis (CEA) plated-wire memory test showed that [redacted]cident on the top plane and a dose gradient through the stack, a radiation pulse will indeed interact with the memory. The observed data showed that the radiation pulse had "written" on the memory; i.e., changed the bit state. On the lowest level exposure, only one state changed, indicating directional coupling, as one might expect from an IEMP.

The IBM closed hard axis (CHA) plated-wire memory test which used a single plane showed that belo[redacted] no effects of any kind were observed. One possible bit reversal and some reduction in amplitude were obser[redacted] indicating that this may be the threshold of interaction for this type of memory.

The passive plated-wire tests gave similar results.

4.4.4 [redacted] Project 2.12, [redacted] Construction[redacted]

The objective was to determine[redacted] damage to Minuteman solid propellant and select construction materials used on ICBMs.

[redacted]

Damage to rocket propulsion materials falls into three basic categories: mechanical, heating, and radiolytic. Examples of these are spallation of materials into the motor, expanding and delamination of liners, gas evolution, cross linking in propellants, and molecular-bond breakage. Samples such as propellants, fiberglass laminates, wire-wound tungsten throats, maraging steel*, zirconium oxide, [redacted]

Posttest examination of the samples did not reveal damage that would be considered detrimental to overall missile performance.

4.4.5 [redacted] Project 2.20d, Mk 3 Cable Experiment.

The objective was to determine [redacted]

Seven cables were exposed at the [redacted] station. Two types, copper coax and flat aluminum, were mounted with various configurations of depleted uranium and polystyrene foam to separate the different effects. All cables were covered with 0.18 g/cm^2 of carbon foam. Four oscilloscopes were used with each cable to record the voltage as a function of time.

Voltages up to [redacted] were recorded with the different configurations giving not only different voltages but opposite polarities. The signals lasted on the order of [redacted] A signal was also recorded at [redacted] arrival and lasted for over a microsecond. Further analysis is being made to identify the source of signals observed between the various configurations. The project objectives were accomplished.

4.4.6 [redacted]

*Ultra high strength steel.

[redacted]

[redacted]

4.4.7 [redacted]) Project 2.40f (SLA), Compton Diode.

The objective was to evaluate a simplified design of a Compton diode as an oscilloscope trigger.

Data were obtained on five Compton diodes exposed at Station 1. The results show that a smaller, simpler than normally used diode, is reliable, that a solid dielectric (rather than oil) can be used, and that a special connector (rather than long pigtails) performed well.

4.4.8 [redacted] Projects 2.20e and 2.40g, EMP Experiments. Both projects were external to the MINUTE STEAK experimental chamber. The descriptions and results of the tests are not of general interest and can be obtained if needed from the Technical Director.

[redacted]

[redacted]

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

[redacted] The degree of success of a field test is determined by the number of objectives which were accomplished. The 41 experiments in MINUTE STEAK had a total of 64 objectives, of which 46 were accomplished, seven will probably be accomplished after all the data have been analyzed, and 11 were not accomplished. Based on the weights given each project (table 3.4) and including the probables, MINUTE STEAK was about 87 percent successful in obtaining its objectives.

5.1 [redacted] EXPERIMENTS.

5.1.1 [redacted] Diagnostics.

The fluence and spectrum were very close to nominal with the consensus being [redacted] at any given station.

The two prime diagnostic experiments agreed relatively well (2.20b and 2.16). The developmental diagnostics were somewhat successful in that the TLDs (2.15) gave good results while the ferroelectric detectors (2.06) failed to respond as expected. The bent crystal (2.13) did well at low energies but not on the high end of the spectrum. Many of the projects did some of their own diagnostics inside their cassettes, and in general these results agreed with the consensus. The small differences in some cases were probably caused by geometry factors created by an extended source.

It is concluded that the prime diagnostics were adequate and satisfied the fourth objective of the test.

There were no time-resolved diagnostic measurements made; however, none of the experimenters expressed interest in this, and so it was unnecessary

[redacted]

5.1.2 [redacted] Systems.

The Poseidon vidicon and gyroscope experiment (2.01a) was inconclusive in that the vidicon support electronics failed before the active data could be obtained.

[redacted]

[redacted]

The passive data indicated that no permanent damage occurred. The gyroscope had a permanent offset of the drift signal. Results were obtained on the semiconductor tests (2.01b) with no failures at the lower level [redacted] The failures, however, were not the type expected; i.e., bond and die damage, but rather die-down/substrate separation and internal solder spall.

Minuteman experiments obtained good results. Four possible radiation failures, out of 26,000 devices, were found in the semiconductor tests (2.02a) which could be significant since they were [redacted] The computer exposed [redacted] 02b) survive [redacted] The computer at [redacted] o circumvent properly, but a red signal hostile detector has eliminated this problem. Other Minuteman experiments, such as materials and components (2.02c and 2.02) turned up no unexpected problems.

The results of the Spartan IEMP experiment (2.07b) indicate that this phenomenon could be a serious threat and should be investigated further. The Spartan semiconductor test (2.08b) also gave good results, showing the actual probability of failure curve is very close to predicted.

The ABRES (2.10) and Mk 3 (2.40a) circuits and semiconductor tests obtain a large amount of useful data.

5.1.3 [redacted] Hardening Experiments [redacted] It appears that with current transistor technology, semiconductor devices can be made as hard as needed with respect to thermomechanical damage (2.08a and 2.09a, c, and d). The problem, if there is one, is quality control. The damage mechanism of metallization burnout (2.04) may have been established as valid. It appears that the SEMM shows promise as a 100-percent screen for semiconductor devices although refinement is necessary (2.04a). Also, some of the hardened circuits did not perform as expected and observed in laboratory tests (2.11 and 2.40b).

5.1.4 [redacted] Interaction Experiments.

The magnetic experiments seem to have obtained consistent data and have shed some light on the question concerning whether or not magnetic effects are a creditable damage mechanism (2.05 and 2.09b). Data were obtained, among other things, on the influence of magnetostriction and on switching in plated-wire memories.

[redacted]

[redacted]

IEMP has become an important subject, and the projects which made measurements all obtained good results (2.07a, 2.20d, and 2.40d). Data were obtained on the EMP's dependence on air pressure and on types of material and on different types and arrangements of cables.

Analysis of several rocket motor materials (2.12) revealed no damage that would be considered detrimental to the overall missile performance.

5.2 [redacted] LOS CLOSURE SYSTEM.

The LOS closure system worked as designed. The only problem was the unexplained leakage which did not affect any of the experiments but could have if the wind had not cooperated. There is, of course, the public relations aspect which might be a problem in future tests.

In the discussions of the contingency plan, some thought should be given to the unlikely event that a monitor light indicates either a premature closure or partial closure during the countdown. If this is not taken into consideration until it happens, a false indication of a premature closure could cause degradation of the experiments during the time all the possibilities of what to do are being discussed. [redacted]

5.3 [redacted] GENERAL.

The ground rules concerning the mandatory dry run prior to downhole operations need to be clearly defined so the experimenter knows what is expected of him and even more important so that an experiment is not degraded because of an unnecessary restriction placed on its operation as a result of the Mandatory Dry Run (MDR).

During the 24 hours prior to the shot there were five unexplained cases of instrumentation power loss in the trailer park. These were in Projects 2.07 (twice), 2.05, 2.10, and 9.11. One case, Project 2.05, resulted in damage to 22 oscilloscopes, several amplifiers, and power supplies. Only because of the commendable work of the Bendix instrument repair group was Project 2.05 able to fully participate in the test. Since power loss, both before and after (four on this test; 2.03, 2.10, 9.11, and backup winch power) tests, has been and

[redacted]

[redacted]

[redacted] [redacted]

continues to be a frequent mishap, it might be advisable for a committee to investigate this problem.

Many of the problems in the field were caused by lack of reliable air conditioning equipment in the instrumentation trailers. Furthermore, during the summer months zipper tubing can only be zipped in the early part of the day. The plastic zippers won t zip in the intense heat of the midday desert sun. Field tests in Area 5-11 of the Nevada Test Site are better scheduled later in the fall, winter, or spring than in the summer or early fall.

[redacted]

[redacted]

APPENDIX

REVIEW OF THE EVOLUTION OF THE MINUTE STEAK PREDICTIONS

[redacted]

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[redacted]

SYSTEMS, SCIENCE AND SOFTWARE

30 July 1969

Col. J. Bower
Defense Atomic Support Agency
Test Command, Sandia Base
Albuquerque, New Mexico 87115

Dear Col. Bower:

[redacted] The predictions for the Minute Steak experimental environment have undergone a number of revisions during the past six months. The purpose of this note is to review the various stages of evolution of those predictions so that all concerned have a clear understanding of how the current set of predictions was obtained. It is also useful to consider the possible uncertainties which are inherent in the predictions.

A.1 INITIAL PREDICTIONS

[redacted] The initial predictions were released by S³ on 9 January 1969 (69-008/3SC-56). These predictions consisted of a set of isoflux contours obtained from a series of Monte Carlo (PHOTRAN) calculations. Plots of flux vs slant range at selected angles were included in the document. The calculations were based on the Indigo representation of the [redacted]

A.2 REVISED PREDICTIONS (BASED ON PRELIMINARY CYPRESS RESULTS)

[redacted] Two things occurred following the release of these predictions, [redacted] result, Test Command generated a new set of isoflux contours for tentative planning pur- [redacted]

[redacted] Concurrent with these considerations the Cypress event was executed (12 February 1969) and preliminary results were released. A meeting was held at Test Command on 19 March 1969 to examine the impact of the Cypress results on Minute Steak and to settle the question of whether or not to use helium.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

A.3 FURTHER REFINEMENTS

[redacted] Subsequent to the distribution of the spectra and the flux map, additional information became available. This information is of two forms: a change in the representation of the observed spectrum in Cypress, and a change in the representation of the photoelectric cross sections for lithium.

[redacted]

A.3.2 Effect of Changes in Photoelectric Cross Sections

[redacted]

[redacted] We have not been able to obtain a critical evaluation of the new cross sections. [redacted]e are many data from other sources which tend to split the difference between the old and new McMasters' data. McMasters is certain that the new data are more reliable than those published previously. Our arbitrary conclusion is that an average increase in scattered fluence of 5% over that predicted previously can be expected.

A.4 SUMMARY

[redacted] In the above paragraphs we have discussed many different effects and data representations which can influence the predicted spectra and fluence levels for Minute Steak. In this summary a brief review of these effects is presented and some quantitative estimates of the expected environment are given. In addition, the implications of other recent tests [redacted] are briefly discussed.

[redacted]

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*McMasters, W. H., et al., "Compilation of X-ray Cross Sections," UCRL-50174, January 1967.

[redacted]

[redacted] TABLE OF EXPECTED FLUENCE
(REFERRED TO A PREDICTED VALUE ϕ_o)

[redacted]

[redacted]		
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

We have no valid basis for reducing this discouragingly large uncertainty in the predictions. It is fairly clear that the desire to err in the direction of obtaining more fluence than predicted has been satisfied.

[redacted] Please feel free to comment on the contents of this note and to ask for clarification of any obscure points.

Sincerely yours,

/s/ Chuck

Charles R. Dismukes

CRD:njc

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(Security classification of title, body of [redacted] the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Defense Nuclear Agency Washington, D.C. 20305	2a. [redacted]
3. REPORT TITLE Technical Directors Summary Report	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Directors Summary Report, MINUTE STEAK Event, accomplished on MILD WIND Series.	
5. AUTHOR(S) (First name, middle initial, last name) Paul A. Trimmer, Harry Diamond Laboratories, Connecticut Ave. and Van Ness St., Washington, D.C. 20438. Donald F. Tiano, Nuclear Defense Research Corp., 5301 Central Ave. NE., Albuquerque, New Mexico 87108.	

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
20 November 1972	128	None

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) POR-6546 (WT-6546) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Distrib[redacted]n limit[redacted] U.S. Go[redacted]rnment [redacted]s only[redacted] and Eval[redacted]); 20 [redacted]ember [redacted]. Other [redacted]uests f[redacted]s docu[redacted]t must be [redacted]ed to the [redacted]ector, [redacted]fense Nuc[redacted] Agenc[redacted]Washingt[redacted] D.C. 2030[redacted]

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	DOD/DNA

13. ABSTRACT

[redacted] MINUTE [redacted] The MINUTE STEAK program was des[redacted] systems, subsystems, and component[redacted] Some of the systems which were [redacted] were Poseidon, Minuteman, Mk 3, and Spartan.

[redacted] The test was successful with most of the objectives being attained. The system experiments demonstrated survival at the threat levels and in some cases uncovered problems at higher than threat levels. The success of the transistor hardening program was demonstrated, and a greater understanding of magnetic effects and internal electromagnetic pulse (IEMP) was obtained. The fluence and spectrum were nominal.

[redacted] Caution should be observed in extracting information from this document, since certain paragraphs, figures and tables that are individually unclassified may become classified if consolidated or associated with events in this report.

DD FORM 1473

[redacted]

[redacted]

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
MILD WIND Series						
MINUTE STEAK Event						
Trailer park plan						
Technical Directors Summary Report						

[redacted]